Relationship between Use of Water from Community-Scale Water Treatment Refill Kiosks and Childhood Diarrhea in Jakarta

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Abstract. In developing countries, safe piped drinking water is generally unavailable, and bottled water is unaffordable for most people. Purchasing drinking water from community-scale decentralized water treatment and refill kiosks (referred to as isi ulang depots in Indonesia) is becoming a common alternative. This study investigates the association between diarrhea risk and community-scale water treatment and refill kiosk. We monitored daily diarrhea status and water source for 1,000 children 1–4 years of age in Jakarta, Indonesia, for up to 5 months. Among children in an urban slum, rate of diarrhea/1,000 child-days varied significantly by primary water source: 8.13 for tap water, 3.60 for bottled water, and 3.97 for water kiosks. In multivariable Poisson regression analysis, diarrhea risk remained significantly lower among water kiosk users (adjusted rate ratio [RR] = 0.49, 95% confidence interval [CI] = 0.29–0.83) and bottled water users (adjusted RR = 0.45, 95% CI = 0.21–0.97), compared with tap water users. In a peri-urban area, where few people purchased from water kiosk ($N = 28$, 6% of total population), diarrhea rates were lower overall: 2.44 for well water, 1.90 for bottled water, and 2.54 for water kiosks. There were no significant differences in diarrhea risk for water kiosk users or bottled water users compared with well water users. Purchasing water from low-cost water kiosks is associated with a reduction in diarrhea risk similar to that found for bottled water.

INTRODUCTION

Diarrhea is the second leading cause of global childhood mortality, responsible for an estimated 1.9 million deaths annually.[1] In Indonesia, diarrhea remains the leading cause of infant mortality and the third leading cause of overall morbidity in all age groups,[2] as well as a leading cause of health care expenditures for young children.[3] Modern water and sanitation services have dramatically decreased both the mortality and the morbidity associated with childhood diarrhea in developed countries. However, in developing countries worldwide, ~780 million people lack access to improved drinking water.[4] Households without improved drinking water are disproportionately the poorest and most vulnerable to disease.[5] Although progress has been made as part of the Millennium Development Goals, dwindling supplies caused by water scarcity, climate change, worsening water quality caused by pollution, urban growth, and the deterioration of existing piped water networks threaten to undermine recent progress. Even among those who, using currently existing reporting criteria, have access to improved water, the majority do not have access to high-quality, pathogen-free, safe drinking water.[6] A recent study that accounted for microbial quality and sanitary risk estimated that 1.6 billion people lack safe water worldwide.[7]

Although investment in municipal infrastructure often fails to service the poor, a number of decentralized water treatment solutions have been developed to offer an alternative avenue for accessing safe water. Household-level water treatment has been documented to decrease disease burden, especially diarrhea, in many randomized controlled studies throughout the developing world.[8,9] However, low adoption rates and the large costs required for educating households to use treatment systems have in part limited global implementation of household

water treatment.[10] Unlike household water treatment options, for-profit community-scale water treatment and refill kiosks have grown without external intervention in Indonesia as private entrepreneurs find ways to provide clean water and earn revenue in low-income markets. In Indonesia, these kiosks make use of either ultrafiltration followed by UV disinfection or reverse osmosis treatment to purify and disinfect water. This business model benefits from its ability to extend upon culturally accepted water vending practices, and from marketing for bottled water aimed at a wealthier clientele.

The community-scale water treatment and refill kiosk industry has grown rapidly from its inception in the late 1990s[11] to become the primary drinking water source for 13% of all urban households in Indonesia.[12] To date, no studies have examined the impact of community-level water treatment and refill kiosks on health outcomes, such as the reduction of diarrheal disease. The objective of this study was to investigate the association between use of water refill kiosks and risk of diarrhea among young children in Jakarta, Indonesia. We conducted a longitudinal study in which children's diarrhea status and primary water source were recorded on a daily basis for up to 5 months.

MATERIALS AND METHODS

Study area. The study was conducted in two areas of Jakarta, Indonesia. The first area consists of two sub-districts (Koja and Tanjung Priok) in the North Jakarta Municipality. North Jakarta is a highly congested urban area (9,314 persons/sq km).[13] Although municipal tap water (treated by conventional coagulation, filtration, and disinfection) is piped to this area of the city, most households do not have private connections and instead acquire water from communal taps or purchase water from street vendors,[2] practices that are associated with increased risk of diarrheal disease.[14] In this area, open defecation into sewers is not uncommon, nor is the disposal of untreated wastewater from pour-flush toilets directly into open sewers located near dwellings.[15] The second area, Pejaten Timur, is a peri-urban sub-district in southern Jakarta, which was farmland until recently. Recent growth and an increase in

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population density have been unmatched by an extension of municipal water or sanitation services. Consequently, residents in this peri-urban sub-district continue to rely on groundwater from covered wells with depths of 10–20 m. Although wells are generally covered and privately owned, a recent study conducted by the Indonesian Ministry of Health found that over 80% of the wells are contaminated with *Escherichia coli*[16]; the two areas of Jakarta were selected to represent different environments where water refill kiosks are present.[11]

Child selection. The study sample included a total of 1,000 children 1–4 years of age (500 children from each area). Potential subjects were identified from records collected at public child health centers (*Pusyandu*), which monitor child growth, provide free immunizations, and implement public health and education campaigns in Jakarta. Participants were randomly selected from among the age-eligible patient records collected from all child health centers in each of the two areas of Jakarta. Participating households were given a gift of rice and oil at the beginning of the study and child hygiene products at the end of the study (the equivalent of 10 United States dollars [USD] in value). Verbal consent was granted by community leaders and by the primary care taker of children involved in the study. The families of eight children opted out of the study during the enrollment period; replacements were randomly selected from the child health center records. One head of household perished during the study, requiring us to stop collecting data for one child after 2 months. Participants were enrolled and baseline data were collected during the first 3 weeks of February 2011.

Data collection. Data collection occurred from February to the end of June 2011 to coincide with the rainy season[17] when diarrhea incidence is highest in North Jakarta.[2] All data were collected by trained enumerators in Bahasa Indonesia (the official Indonesian language). Data collection forms were translated from English to Bahasa Indonesia and then back-translated by two different translators to ensure accuracy (any discrepancies were resolved by consensus). A pilot study (consisting of 100 households) was conducted in November–December 2010 in Padang, Indonesia, to validate the accuracy of the survey instruments and to test the data collection methods.

The baseline interview, administered using netbooks to minimize data entry errors, included questions on the socio-demographic characteristics of the child and household, sanitation factors, and child health status. Survey items were modeled on previously validated questions from an economic survey conducted in Indonesia[18]; during the baseline visit, the child's primary caregiver (most often the mother or grandmother) was trained to complete two daily logs. The first log, which used the SMILEY diagram[19,20] translated into Indonesian, was used to track the number of loose stools the child had and whether blood or mucous was present every day of follow-up. The second log was used to track the child's main drinking water source (i.e., tap water, well water, bottled water, or water kiosk) as well as household water treatment (i.e. boiling) every day of follow-up. Daily logs were collected between 119 and 133 days per child. Enumerators collected log sheets on a weekly basis and verbally confirmed information on the sheets with the caregiver. Data from the logs were recorded electronically by the enumerators on the day they were collected, and data entry was periodically verified by field managers. A randomly selected 10% subset of the log sheets was further validated by separate data entry specialists who compared the collected sheets with the corresponding electronic records; < 1% of the log sheets had an error in data entry.

Measures. The independent variable of interest was the child's primary water source over the course of follow-up. Using the daily logs, we determined whether any water source—tap water, well water, bottled water, or water kiosk—was reported on $\geq$ 90% of days; if so, that was regarded as the "primary" water source. If no one water source was used on $\geq$ 90% of days, the household was then categorized as using a combination of water sources. In this study, tap water refers to municipal tap water collected at neighborhood taps or purchased from street vendors. Well water refers to water collected from deep, covered wells. Bottled water refers to packaged branded water sold in bottles at supermarkets and other shops. Water kiosk refers to water from the community-scale water treatment and refill kiosks (referred to as isi ulang depots in Indonesia) introduced in this work.

The dependent variable of interest was rate of diarrhea. Consistent with previous studies,[21] diarrhea was defined as having three or more loose stools or a loose stool containing blood or mucous in a given day. Rate of diarrhea was calculated by dividing the total number of diarrhea-days (numerator) by the total number of child-days of follow-up (denominator). All rates are reported per 1,000 child-days.

Sociodemographic and sanitation covariates were defined based on caregiver responses to the baseline questionnaire. These included the child's sex and age; the total number of household members, including the sample child; whether the household fell below the poverty line, defined as a household income of < 233,740 Rp (25.60 USD) per capita per day[22]; the sanitation facilities available to household members; and the highest level of education completed by the head of the household. Sanitation facilities are categorized to mirror the Joint Monitoring Program (JMP) sanitation ladder.[4] Specifically, we categorize families as having access to private sanitation that is improved (pour-flush systems to septic tank), shared or public access to improved sanitation (including pour-flush systems treated by septic tanks and pour-flush pit latrines), or unimproved systems (pour-flush to open sewer or defecation into surface water). Household water treatment via boiling is commonplace in Indonesia.[23] We use daily log data to calculate the number of days that a child received untreated water (water that was neither boiled nor poured from a branded bottle or water or a refill water kiosk). The covariate reported is the rate of the number of days a child is provided untreated water (numerator) by total number of child-days of follow-up (denominator). All rates are reported per 1,000 child-days.

Data analysis. The analysis for this study proceeded in three steps. First, we characterized the two study locations (northern urban slum area and southern peri-urban area of Jakarta) with respect to the study variables of interest. Between-group differences were analyzed using the χ^2 or Fisher's exact test for categorical variables, the *t* test for continuous variables, and Poisson regression for diarrhea rate. Second, differences in the distribution of sociodemographic, boiling, and sanitation covariates by primary water source were examined, in each location separately, using either the χ^2 test or the analysis of variance F-test, as appropriate. Finally, in each study location, the association between primary water source and rate of diarrhea was examined using Poisson regression analysis with an offset for the logarithm of

the number of follow-up days per child. Unadjusted and adjusted rate ratios (RRs) and 95% confidence intervals (CIs) are presented. In multivariate analyses, adjustments were made for all sociodemographic, boiling, and sanitation covariates described in the Measures section previously. SAS version 9.2 (SAS Institute Inc., Cary, NC) was used to conduct the analyses.

Ethical clearance. Research clearance was granted by the Yale University Human Investigation Committee, the Secretary of Foreign Research Permits in the Indonesian Ministry of Research and Technology (Sekretariat Perizinan Peneliti Asing, Kementterian Riset Dan Teknology, Jakarta, Indonesia), and the Jakarta Governor's Office Department of Population Research Ethics Committee. Verbal consent and collaboration was provided by staff at the public child health centers (*Pusyandu*), and by community leaders in the selected neighborhoods. Oral informed consent was obtained from the legal guardian of all children included in the study before baseline data collection.

RESULTS

Table 1 describes the significant differences among households in the two study locations. Children in the northern urban slum are more likely to come from households that are below the poverty line than children in the southern peri-urban area ($P < 0.001$). The children in the northern area are also more likely to come from households whose household head is less well educated than those children in the southern peri-urban area ($P < 0.001$). Furthermore, children in the northern area are more likely to consume water purchased from water refill kiosks ($P < 0.001$) and have less access to private, improved sanitation facilities ($P < 0.001$) than children in the southern area. Diarrhea was monitored for a total of 126,868 child-days. The rate of diarrhea is higher in the northern area than in the southern area ($P < 0.001$).

In the northern area, 28% of the children are classified as tap water consumers, 13% are bottled water consumers, 30% are community-scale water treatment and refill kiosk consumers, and 29% use a combination of water sources (Table 1). Table 2 illustrates the distribution of sociodemographic and sanitation factors by primary water source by study location in Jakarta, Indonesia. In the northern area, we find that household poverty ($P = 0.004$), sanitation access ($P < 0.001$), and household head's level of education ($P < 0.001$) vary significantly among the water source groups. In the southern area, 40% of the cohort was classified as using well water, 16% of the population was classified as using bottled water, 38% of the population was using a mixed variety of water sources, and only 6% of the population was regularly purchasing water from refill stations (Table 1). In this area, access to sanitation and household head's level of education did not vary significantly among different water sources (Table 2). However, poverty level was significantly different among the groups ($P = 0.001$)—the number of bottled water consumers that live below poverty is the lowest, whereas the number of well water consumers living below poverty is the largest.

Table 3 describes the results of the Poisson regression analysis of the association between primary water source and rate of childhood diarrhea by study location in Jakarta, Indonesia. The rate of diarrhea (per 1,000 child-days) in the northern urban slum sub-district is 8.13 for those using tap water, 3.60 for those using bottled water, 3.97 for those using community-scale water treatment and refill kiosk water, and 5.07 for those using mixed water sources. Both the consumption of bottled water and the consumption of community-scale water treatment and refill kiosk water are associated with a reduction in the risk of diarrhea in our sample cohort; the unadjusted RR estimates are significantly lower in the bottled water and refill station groups, compared with those consuming tap water. Controlling for a number of potential confounders, including child age, family income, household water treatment, and household sanitation

TABLE 1
Description of the sample by study location in Jakarta, Indonesia*

	Northern urban slum area ($N = 500$)	Southern peri-urban area ($N = 500$)	P value†
Child's sex female, n (%)	257 (52%)	256 (51%)	0.999
Child's age in months, mean (±SD)	35 (±14)	32 (±13)	0.002
Household size, mean (±SD)	4.9 (±1.9)	4.6 (±1.6)	0.004
Household is below poverty line, n (%)	289 (58%)	126 (25%)	< 0.001
Untreated water rate 1,000 child-days, mean (±SD)	1.0 (±7.3)	1.2 (±7.9)	0.406
Head of household's education level			< 0.001
Less than primary school, n (%)	131 (26%)	83 (17%)	
Completed primary school, n (%)	145 (29%)	117 (23%)	
Secondary school or greater, n (%)	224 (45%)	300 (60%)	
Primary water source			< 0.001
Well water, n (%)	0 (0%)	202 (40%)	
Tap water, n (%)	142 (28%)	0 (0%)	
Bottled water, n (%)	64 (13%)	79 (16%)	
Water kiosk, n (%)	148 (30%)	28 (6%)	
Combination, n (%)	146 (29%)	191 (38%)	
Household sanitation facilities			< 0.001
Private improved, n (%)	204 (41%)	464 (93%)	
Shared/public improved, n (%)	232 (46%)	21 (4%)	
Unimproved, n (%)	60 (12%)	13 (3%)	
Incidence of diarrhea			
Total diarrhea-days	343	149	
Total child-days of follow-up	63,192	63,676	
Rate/1,000 child-days	5.43	2.34	< 0.001

*Numbers may not sum to total because of missing data and percentages may not sum to 100% because of rounding.
† P value for χ^2 or Fisher's exact test (categorical variables) or t test (continuous variables).

TABLE 2

Distribution of sociodemographic and sanitation factors by primary water source and study location in Jakarta, Indonesia*

		Tap water	Bottled water	Water kiosk	Combination	
		N = 142	N = 64	N = 148	N = 146	P value†
Northern urban slum area	Child's sex female, n (%)	59 (47%)	39 (61%)	73 (49%)	75 (53%)	0.297
	Child's age in months, mean (±SD)	38 (±13)	32 (±13)	36 (±15)	33 (±15)	0.013
	Household size, mean (±SD)	5.0 (±1.8)	4.6 (±1.5)	5.0 (±2.2)	4.8 (±1.9)	0.495
	Household is below poverty line, n (%)	98 (70%)	29 (46%)	86 (59%)	76 (52%)	0.004
	Untreated water rate/1,000 child-days, mean (±SD)	1.6 (±9.1)	0.4 (±3.0)	0.7 (±5.3)	0.9 (±8.4)	0.649
	Head of household's education level					< 0.001
	Less than primary school, n (%)	58 (41%)	13 (20%)	34 (23%)	26 (18%)	
	Completed primary school, n (%)	51 (36%)	14 (22%)	47 (32%)	51 (35%)	
	Secondary school or greater, n (%)	33 (23%)	27 (58%)	67 (45%)	69 (47%)	
	Household sanitation facilities					< 0.001
	Private improved, n (%)	37 (26%)	35 (55%)	62 (42%)	70 (48%)	
	Shared/public improved, n (%)	89 (63%)	25 (39%)	60 (41%)	58 (40%)	
	Unimproved, n (%)	15 (11%)	3 (5%)	25 (17%)	17 (12%)	

		Well water	Bottled water	Water kiosk	Combination	
		N = 202	N = 79	N = 28	N = 191	P value†
Southern peri-urban area	Child's sex female, n (%)	100 (52%)	37 (47%)	12 (43%)	107 (53%)	0.629
	Child's age in months, mean (±SD)	33 (±13)	32 (±13)	30 (±12)	32 (±14)	0.743
	Household size, mean (±SD)	4.9 (±1.8)	4.3 (±1.6)	4.4 (±1.5)	4.3 (±1.3)	< 0.001
	Household is below poverty line, n (%)	67 (33.2%)	9 (11.4%)	6 (21.4%)	44 (23%)	0.001
	Untreated water rate/1,000 child-days, mean (±SD)	0.5 (±4.4)	0.7 (±3.7)	0.0 (±0.0)	2.4 (±11.7)	0.091
	Head of household's education level					0.068
	Less than primary school, n (%)	37 (18%)	9 (11%)	2 (7%)	25 (18%)	
	Completed primary school, n (%)	116 (57%)	12 (15%)	11 (39%)	111 (58%)	
	Secondary school or greater, n (%)	49 (24%)	58 (73%)	15 (54%)	45 (24%)	
	Household sanitation facilities					0.549
	Private improved, n (%)	182 (92%)	72 (91%)	25 (89%)	182 (95%)	
	Shared/Public Improved, n (%)	11 (5%)	4 (5%)	1 (4%)	5 (3%)	
	Unimproved, n (%)	6 (3%)	2 (2.5%)	2 (7%)	3 (2%)	

*Numbers may not sum to total because of missing data and percentages may not sum to 100% because of rounding.
†P value for χ^2 test (categorical variables) or analysis of variance F-test (continuous variables).

access, we find that the decreased risks associated with the purchase of bottled water (adjusted RR = 0.45, 95% CI = 0.21–0.97) and community-scale water treatment and refill kiosk water (adjusted RR = 0.49, 95% CI = 0.29–0.83) remain statistically significant (Table 3).

Overall, the rates of diarrhea (per 1,000 child-days) were lower in the southern area, with 2.44 for children who consume well water, 1.90 for children who consume bottled water, 2.54 or children who consume community-scale water treatment and refill kiosk water, and 2.39 for children who consume a combination of water sources (Table 3). Both unadjusted and adjusted Poisson regression models do not show any significant differences in diarrhea risk among the water sources in the southern area.

Of the confounding variables considered in the multivariate model, age in months is significantly inversely related to larger rates of diarrhea in both the northern (P = 0.0001) and southern (P < 0.0001) study areas. Additionally, in the north, where the overall rates of diarrhea were higher, we found that the increased family member number was associated with a larger relative rate of diarrhea (P = 0.0799), and that the use of public or shared facilities (in contrast to private facilities) was associated with an increase in relative rate of diarrhea (P = 0.0548).

TABLE 3

Poisson regression analysis of the association between primary water source and rate of childhood diarrhea by study location in Jakarta, Indonesia

		Tap water	Bottled water	Water kiosk	Combination
		N = 142	N = 64	N = 148	N = 146
Northern urban slum area	Total diarrhea-days	146	29	74	94
	Total child-days of follow-up	17,954	8,055	18,640	18,543
	Rate per 1,000 child-days	8.13	3.60	3.97	5.07
	Unadjusted rate ratio (95% CI)	1.00	0.44 (0.19–0.98)	0.49 (0.28–0.86)	0.63 (0.37–1.05)
	Adjusted* rate ratio (95% CI)	1.00	0.45 (0.21–0.97)	0.49 (0.29–0.83)	0.61 (0.37–1.01)

		Well water	Bottled water	Water kiosk	Combination
		N = 142	N = 64	N = 148	N = 146
Southern peri-urban area	Total diarrhea-days	63	19	9	58
	Total child-days of follow-up	25,863	9,978	3,549	24,286
	Rate per 1,000 child-days	2.44	1.90	2.54	2.39
	Unadjusted rate ratio (95% CI)	1.00	0.78 (0.32–1.92)	1.04 (0.31–3.55)	0.98 (0.52–1.83)
	Adjusted* rate ratio (95% CI)	1.00	0.89 (0.38–2.09)	0.98 (0.31–3.09)	1.03 (0.57–1.87)

*Adjusted for child's sex, child's age in months, household size, whether household income per capita is below poverty, household's sanitation facilities, and head of household's education level.
CI = confidence interval.

The rate of untreated water provided to the child, poverty status of the household, education of the household head, and sex of the child were not significant predictors of diarrhea rate in this data set. In the southern area, where the overall rate of diarrhea was lower, none of the covariates, with the exception of child sex ($P = 0.0230$, larger rate for boys), were significantly associated with diarrhea rates.

DISCUSSION

This is the first study to report the association between the use of community-scale water treatment and refill kiosks and childhood diarrhea rates. The adjusted rate of diarrhea for those purchasing bottled water (0.45 [0.21–0.97]) and refill kiosk water (0.49 [0.29–0.83]) are both significantly lower than for those using tap water in the northern urban slum area. The results parallel trends in Ghana, where the consumption of locally treated water sold in sachets was associated with a reduction in diarrhea.[24] No significant association was found between primary water source and diarrheal disease in the peri-urban area where, compared with the urban slum, use of water kiosks was significantly lower (6% versus 30%, $P < 0.001$), as was the overall rate of diarrhea (2.34 versus 5.43 per 1,000 child-days, $P < 0.001$).

A number of interventions have been proposed to reduce the incidence of diarrheal disease in low-income settings. Most interventions that increase access to improved water sources (i.e., protected springs, covered wells, communal tap stands) report small, 15–17% reductions in diarrheal disease.[25,26] Recontamination in the home or during transportation is known to be a major concern, especially when residual disinfectant is not used at the source.[8] Household-level water treatment has been more effective, reducing diarrheal disease risk by almost 40%, likely because water is treated before consumption and recontamination is avoided.[9] Community-scale water treatment and refill kiosk water provision avoids recontamination after water treatment as water is stored in large sealable water bottles with tops.

In Indonesia, household-level water treatment interventions, particularly those relying on chlorination at the household, have faced serious challenges caused by cultural aversions to the taste of chlorine.[27] Boiling is practiced nearly universally in Indonesia,[23] and has been associated with improved water quality as measured by less frequent presence of *E. coli*.[27,28] However, boiling alone may be an insufficient solution, as product water is still contaminated,[26,28] possibly caused by unsafe water management, including mixing hot boiled water with cool untreated water to facilitate cooling.[29] Water treatment interventions, including point-of-collection water quality improvements, boiling in the household, and household disinfection using chlorine face implementation challenges in Indonesia.

Community-scale water treatment and refill kiosk have become popular in Indonesia, supplying between 5% and 35% of the urban population in different cities with drinking water.[12] The water kiosk sector is also growing rapidly in Thailand and the Philippines.[30] A social for-profit company, WaterHealth (Hyderabad, India), is using a similar model to supply 4 million villagers in Bangladesh, Ghana, India, Liberia, Nigeria, and the Philippines with clean drinking water.[31] Several nonprofit organizations, including Naandi Foundation, Safe Water Network, and Aquaya Foundation are also working to develop community-scale water treatment and refill kiosk to address urban and rural water needs.[10] The findings of our study suggest that growth of this industry may benefit child health. Bottled water is over four times more expensive than water from refill kiosks in Jakarta.[11] Thus, water refill stations may be an attractive alternative for low-income populations in urban areas with unsafe tap water.

It is important to acknowledge limitations of this study. First, the sample may not have been representative of all young children in the northern and southern Jakarta study areas, because recruitment was based on health records from public community health centers, which disproportionately treat poorer children.[2] Second, data were collected in two areas of Jakarta, thus potentially limiting the generalizability of the findings. Third, we had insufficient power to detect differences in diarrhea rates in the south, where diarrhea rates were lower and the number of water kiosk users was also lower. As water kiosk use continues to increase in Indonesia and elsewhere, further studies are needed to understand their role in improving health outcomes.

In conclusion, among children in a Jakartan urban slum, rate of diarrhea was significantly lower among both bottled water users and community-scale water treatment and refill kiosk users, compared with tap water users, even after controlling for sociodemographic and sanitation factors. Purchasing water from community-scale water treatment and refill kiosk is associated with a reduction in diarrhea risk similar to that found for bottled water. Thus, water refill stations may be a cost-effective alternative in urban areas with unsafe tap water.

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